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ABSTRACT

Until the rise of cognitive psychology, models of the teaching-learning process (TLP) stressed external rather than internal variables. Models remained general descriptions until control theory introduced explicit system analyses. Cybernetic models emphasize feedback and adaptivity but give little attention to creativity. Research on artificial intelligence and transformational grammar indicates the importance of generative processes in intelligence systems. A model, Generative Model of the Teaching-Learning Process (GENTL), expands the early Test-Operate-Test-Exit (TOTE) unit into a monitor and three subsystems--designer, executor, and adaptor--each isomorphic with the overall system, thereby permitting recursion of generic functions. Such a model has support in TLP literature and suggests a generative approach to teacher training. (Author)

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Toward a Generative Model of the
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Urged by the scientific community to become more precise and clear, educational research has made numerous attempts to model the teaching-learning process (TLP). A seminal article by Gage in the first Handbook of research on teaching (1963) compared a variety of paradigms, but none has captured the attention of researchers at large. At about the same time, however, Glaser advanced a simple model drawn from experience in military training systems and strongly influenced by behavioristic learning theory (Glaser, 1962). This model, amplified by Gagne (1970) and popularized by texts such as DeCicco (1968) and Anderson and Faust (1973), has had a wide impact upon educational research and development and continues to guide teacher training at many institutions.

The Glaser model follows the procedures of operant conditioning: (1) define the final performance (instructional objectives), (2) determine the operant level (entering behavior), (3) introduce contingencies of reinforcement (instructional procedures), and (4) measure operant strength (performance assessment). Gagne stressed that the first step involves both task description and task analysis, the latter producing a hierarchy of learning prerequisites. The fourth step leads back to each of the preceding three, furnishing data by which to modify decisions regarding the learning hierarchy, the placement of students within the hierarchy and the environment that mediates instruction.

Another model proposed at about the same time by Carroll (1963) has had a wide appeal. Five key variables account for learning, all associated with the central variable, time. Three are student characteristics: aptitude (required time), perseverance (time-on-task or spent time), and ability to understand instruction (well-used time). The other two are teacher (school) characteristics: opportunity to learn (allowed time) and quality of instruction (well-structured time). Carroll's model has given impetus to proposals for mastery learning (Bloom, 1968; Block, 1971), and empirical support has appeared for the "opportunity to learn" variable in Husen's international study of comparative education (cf. Walker and Schaffarzick, 1974).

The emphasis in both Glaser's and Carroll's models is on external variables. The major stress in the latter, as in schools traditionally, is on input. However, the major input variable in Carroll's model, unlike traditional schooling, is time. Achievement is viewed as a function of time broadly interpreted to include individual differences variables like ability to understand instruction and quality of instruction. The Glaser model, on the other hand, focuses on output. Objectives are dominant, initiating

and guiding the development of instruction. Individual differences also play a role, e.g. in phase two and presumably in the modifications set in motion by phase four, but the major variables are overt in the curriculum and the teaching environment. Achievement is linked to clearly measurable and validly sequenced outcomes.

The search for a coherent TLP model has given rise more recently to models with a broader scope. Like cognitive psychology, these models include internal variables like mechanisms for decoding, encoding, memory and other information-processing tasks. These mechanisms usually appear in a flow-chart that proceeds from sensory input to long-term storage and rule-governed output (cf. Gagne, Gage and Berliner, 1975). In most cases these charts tend to represent the learner rather than the teaching-learning process. The difficulty in integrating the teacher and the learner is apparent in the fact that most so-called TLP "models" are only general descriptions in which the boxes and the arrows (when they appear at all) refer to global processes and outcomes, not system elements in dynamic interaction (cf. Joyce and Weil, 1972; Nuthall and Snook, 1973).

Until the advent of the modern computer, it was nearly impossible to represent a richly complex and changing process in anything but static terms. Cybernetics and control theory have furnished a means of communication in which internal variables can be made explicit without distorting their dynamic character. In particular, computers reveal the critical role of feedback in transforming input into the desired output. By calling upon clearly specified optimization routines, a computer program is able to adapt the processing of crude initial data (entering behaviors) and make the outcome far more sophisticated than a linear flow chart from initial point A to final point B would suggest. In Carroll's terms, time is better structured, the quality of the transformational (instructional) process is higher, and time requirements are smaller when the TLP makes use of cybernetic principles.

An early application of control theory to psychological processes was the TOTE unit (test-operate-test-exit) or Plan (Miller, Galanter and Pribram, 1960). A TOTE consists essentially of two functions; checking and correcting data. The unit was proposed as an alternative to the stimulus-response (S-R) bond as the underlying structure of behavior. The order of events in a TOTE is somewhat the reverse of an S-R bond. A test of congruence between data and expectations occurs <u>before</u> action (response) rather than being contingent upon <u>it</u>. Action - the operate phase - seeks to reduce discrepancies and leads back to the test phase. The effect of this incongruity - reduction loop is to emphasize a cognitive element at the basis of behavior, similar to the comparator function of a computer.

An application of cybernetics to instruction was reported in the early Gage (1963) article and has been simplified by Stolurow (1965). The comparator function in Stolurow's SOCRATES model occurs in two capacities, as "teacher" and "professor". The latter does a preliminary and on-going search for suitable learning experiences (programs), while the "teacher" implements the program and monitors student performance. Prior to these "tutorial" functions, SOCRATES carries out a pretutorial phase, which makes the initial match between student and curriculum. The "professor" represents an extension of pretutorial decision-making into the teaching-learning exchange. As Gage subsequently pointed out (Gage and Unruh, 1967), the pretutorial-tutorial distinction coincides with the distinction between preactive and interactive teaching in Jackson's description of teachers as information-processors (Jackson, 1966), an indication that as a model takes on dynamic properties it draws closer to formulations drawn from observing teacher activity.

Important as the comparator function and feedback are in a TLP model, an additional property is essential if the model is to mirror what goes on in a teaching-learning situation. Advances in computer science and linguistics have led to a recognition that an intelligent system does more than process information and adapt to the environment. It is generative, capable of novel responses through creative transformations of input. Moreover, a generative process expands productivity. The principle of maximizing output with a minimum of input permits the process to unfold far beyond its initial state.

Generativity can take many forms. Chomsky distinguishes between weak and strong generative capacity, the latter yielding structural descriptions of sentences rather than the sentences themselves (Chomsky, 1965). A generative grammar can be weak, permitting a speaker to generate sentences intuitively in accordance with a system of rules, or it can be strong in that the speaker not only has this basic competence but can generate the underlying syntax. Presumably, with strong generativity (control of deep structure), the range of alternative surface structures (sentences) expands and creative output becomes more likely.

Chomsky also points out that the key to generativity is a system of recursive processes, which is "how a languate can (in Humboldt's words)'make infinite use of finite means'" (Chomsky, 1965, p. 8). Recursion has become a powerful tool in list-processing computer languages that have made possible research on artificial intelligence (Minsky, 1968; Weissman, 1965). Fundamental to such languages is a "push-down stack" that stores the path and intermediate results of a routine as it calls itself (recurs) in the course of carrying out its work. Through the theoretically endless calling of itself, a process can generate the kind of open-ended, unanticipated outcomes that are characteristic of human behavior.

To explore the possibility of a recursive, generative model of teaching and learning, let us consider a model called GENTL (Figure 1). The basic structure resembles a TOTE unit in which a flow of information passes from previously encountered systems (e.g. home, television and peer groups as well as teachers and classrooms) into a top-level control unit called the monitor for an initial test. The monitor either passes the information on or calls up a series of operations if the test reveals a discrepancy in the information. These operations seek to remove the discrepancy, but in doing so they also apply tests, make decisions, and perform sub-operations.

Though Miller, Galanter and Pribram distinguish between a TOTE (Plan) and an Image, the monitor incorporates the Image into the Plan. They mean by Image the world view in which the system or organism organises knowledge about its world. The Image contains data; it is the cognitive structure, the internal representation of the world, the underlying belief system. The Plan operates upon data; it is the program that sequences actions and transforms information. Both are essential ingredients in a generative model just as they are in a computer program and any language. Computer procedures need a data base; grammers need a lexicon.

The Image resides in the monitor through two primary components: memory and expectancy. Knowledge about the past, encoded in memory, interacts with standards and values to produce expectancy. The monitor tests incoming information by what it remembers and what it expects. To deal with discrepancies of either type, the monitor establishes policy. The cost of the discrepancies must be weighed against the cost of dealing with them. Relative priorities must be assigned and the rules of operation, or syntax, must be set. Finally a work queue must specify which tasks will receive resources and attention in what order.

It is not always clear to the classroom teacher that he or she is a policy-maker, nor is it always clear to administrators and curriculum developers that theirs is not the sole prerogative to set policy. GENTL points out that policy decisions are fundamental at all levels of the TLP, and attempts to set policy that disregard the belief system of the teacher in the field will probably do little to alter actual teaching.

Below the monitor is a series of subsystems that form a binary-adaptive loop (BAL). This loop is the Plan or program that is available to carry out teaching and learning. Like the SOCRATES model, GENTL has a pretutorial, preactive phase and a tutorial, interactive phase. The TOTE unit did not specify this two-phased structure, but the authors illustrate the recursive character of their TOTE conception (TOTEs consisting of TOTEs) by noting Woodworth's reference to "two-phase motor units" (Miller, Galanter, Pribram, 1960, p. 32; cf. Woodworth, 1958). Behavior often occurs in two stages: preparation (flexing, crouching, opening) and consummation (lifting, jumping, grasping). Teaching requires a time for planning and a time for execution of the plans.

The preactive phase is represented in GENTL by the design subsystem, but the execution phase includes three subsystems as the result of two binary splits - two divisions of function. The first division is between the transmitting agent and the transforming agent, who are joined in transaction. The execution phase, or more properly the transaction phase, begins with a source of information flow that is to be changed, i.e. a learner. The design system prepares for the learner, and the presence of the learner sets the stage for the transformer. The second division is within the transformer, between the delivery stage and the stage of evaluation. Transactions during the delivery of instruction set the stage for the culminating work of adapting the entire range of operations within the loop to individual differences that exist not only among learners but also among designers and media of instruction. The loop then passes the information flow back to be tested by the monitor.

The four subsystems of the BAL are in effect the four stages of Glaser's model under monitor control. Like Glaser's model, GENTL permits bypassing of stages. Teachers can ignore the design task or the learner's entering level and proceed directly to delivery with little, if any, evaluation. The success of such a strategy, however, is doubtful, especially if pupil competence is the goal. An adaptive strategy, one that transforms student behavior, requires attention to each component of the fully articulated TLP.

Differences between GENTL and the Glaser model arise from the fact that GENTL views the TLP as a dynamically interrelated and generative system. The interrelationships within GENTL resemble biological and physical systems, but since the emphasis of the TLP is on human behavior, particularly language behavior, it would be more appropriate to draw analogies with systems like computer software and the world of the theater. The process of communicating with (teaching) a computer usually follows four steps: designing and writing code in the source language, compiling the code, loading and executing the program, and debugging. If writing the code is like preparing a lesson, compilation is like fitting the code (lesson) to a particular computer (student), taking into account the structure, capacity, and configuration of resources to which the code (lesson) is being directed. Lesson delivery corresponds to running (executing) the compiled code. In a learning system, execution ordinarily results in failures or "bugs" either in the code (lesson) or the computer (student) or both. The debugging phase supplies corrective feedback for redesign of both the lesson and the student's behavior.

A similarly interdependent system is found in the dramatic world, where writer collaborates with (1) producer, who tailors the play to a particular audience and set of circumstances, (2) director, who interacts through actors with the audience, and (3) critic, whose reactions - actual and anticipated - guide both strategic and tactical decisions.

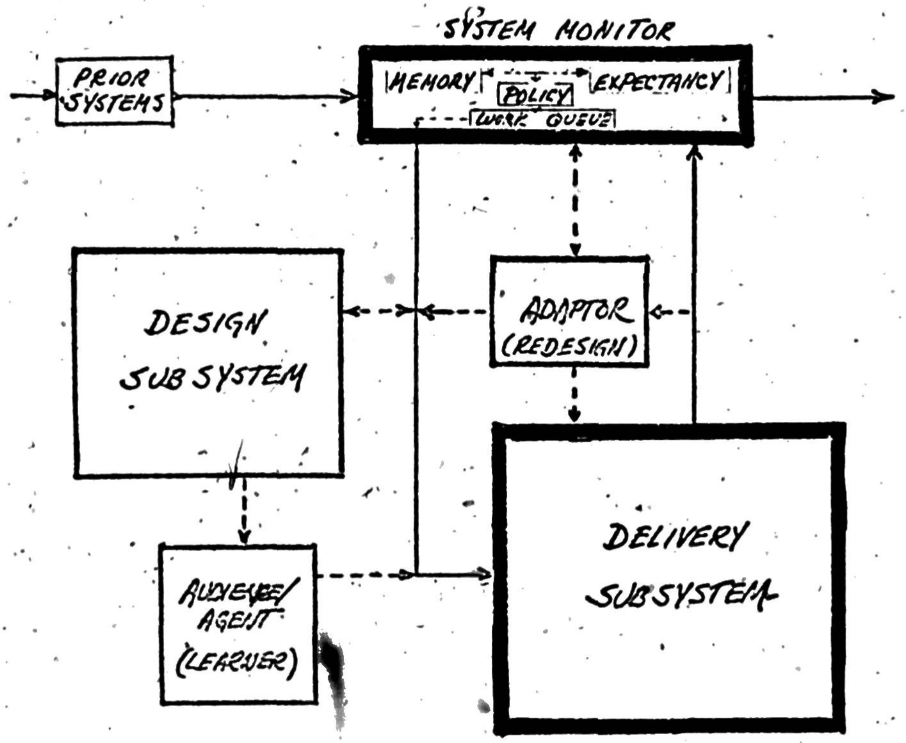

Figure 1. GENTL model of the teaching-learning process. Subsystems below the monitor form a binary-adaptive loop (BAL) that operates on an information flow that is discrepant with monitor expectations. Boxes with heavy lines are essential subsystems; broken connecting lines denote suggested but not required paths.

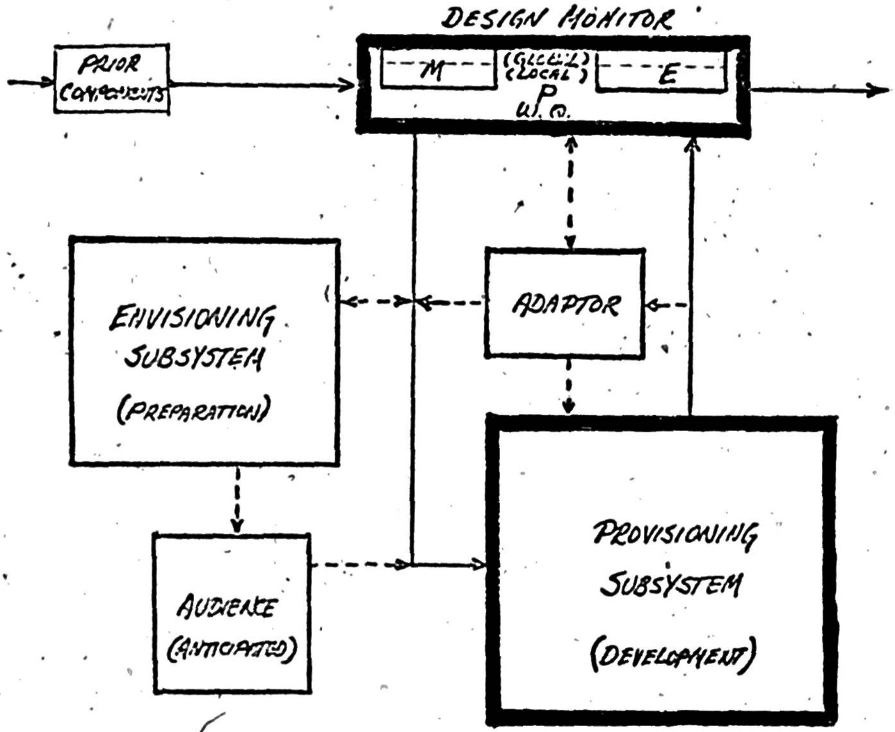

Figure 2. Design subsystem of the GENTL model (Fig. 1). Though ordinarily accessed first within the top-level BAL, this subsystem may be activated by any of the other components within the model because of the recursive character of the generic functions of GENTL. Broken lines within the design memory (M) and design expectancy (E) separate data common to all GENTL subsystems (global) from that which is unique to the design monitor (local).

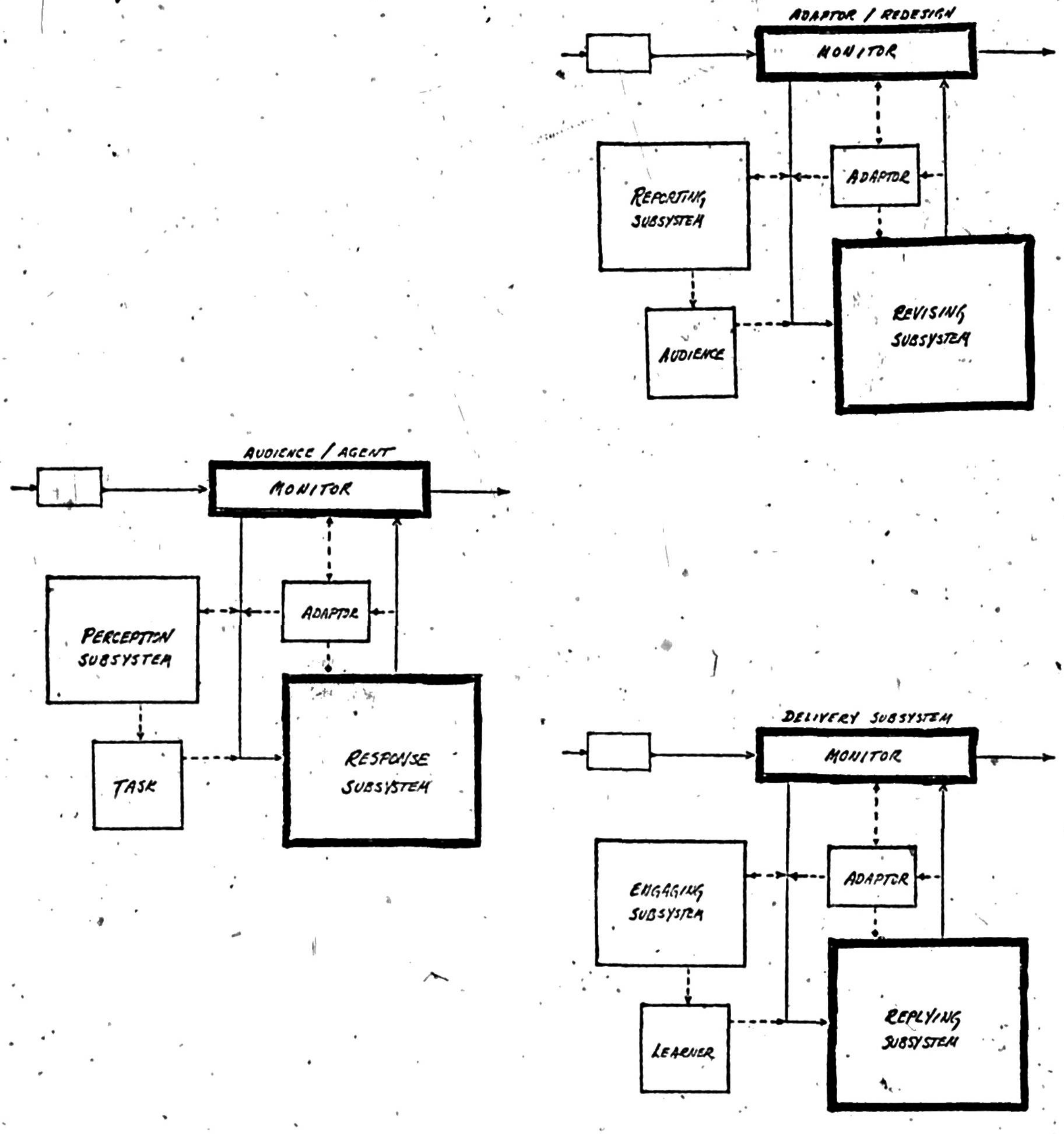

Figure 3. Agent, delivery, and adaptor subsystems that complete the top-level BAL within GENTL after information is passed from the design subsystem (Fig. 2).

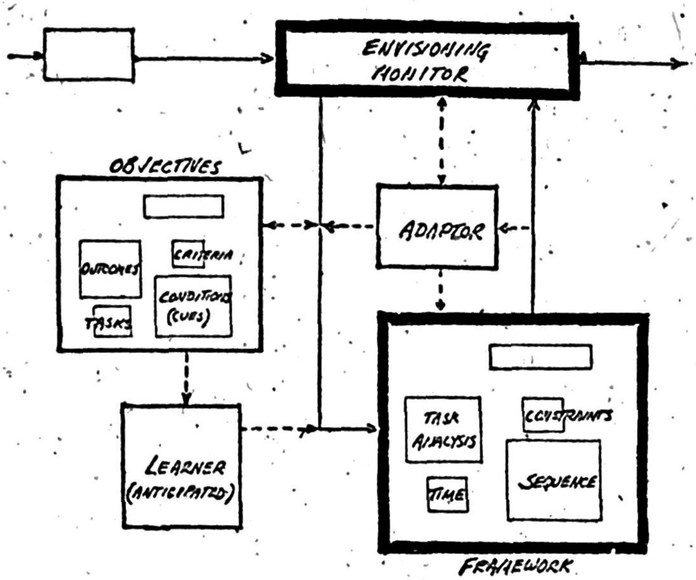

Figure 4. The envisioning subsystem in GENTL.

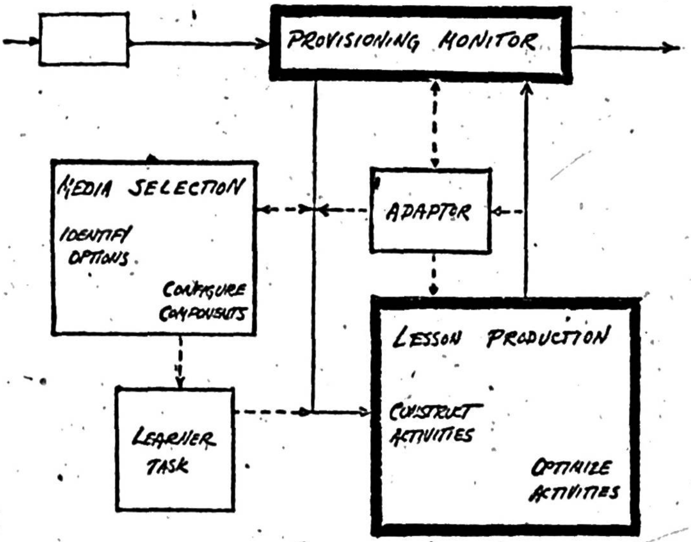

Figure 5. The provisioning subsystem in GENTL.

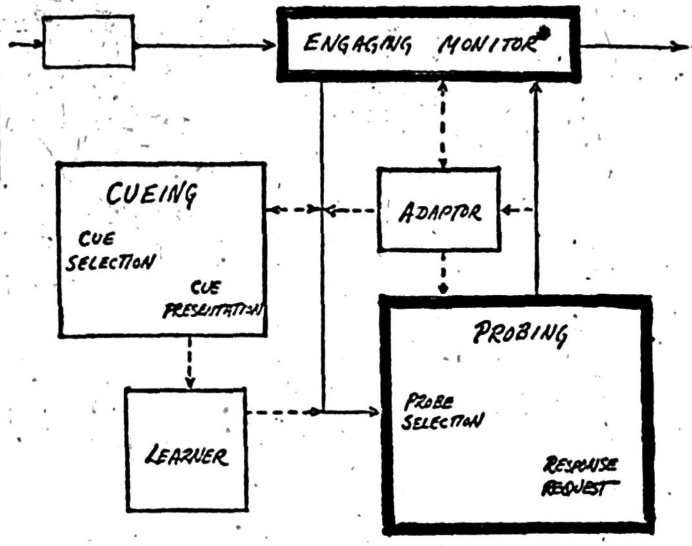

Figure 6. The engaging subsystem in GENTL.

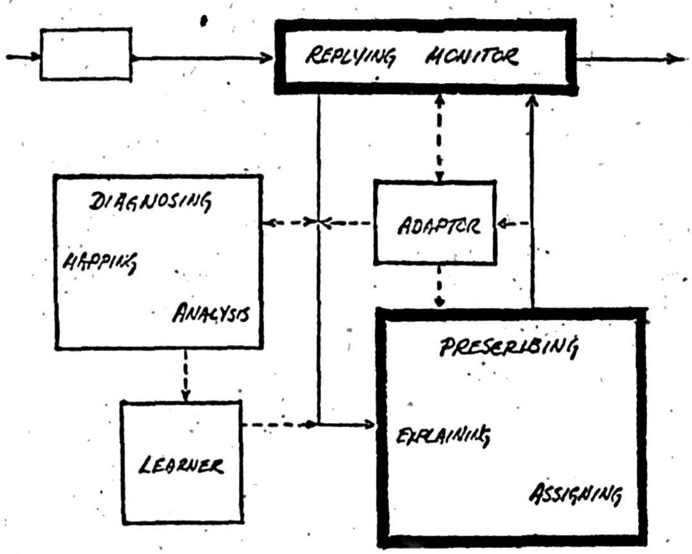

Figure 7. The replying subsystem in GENTL.

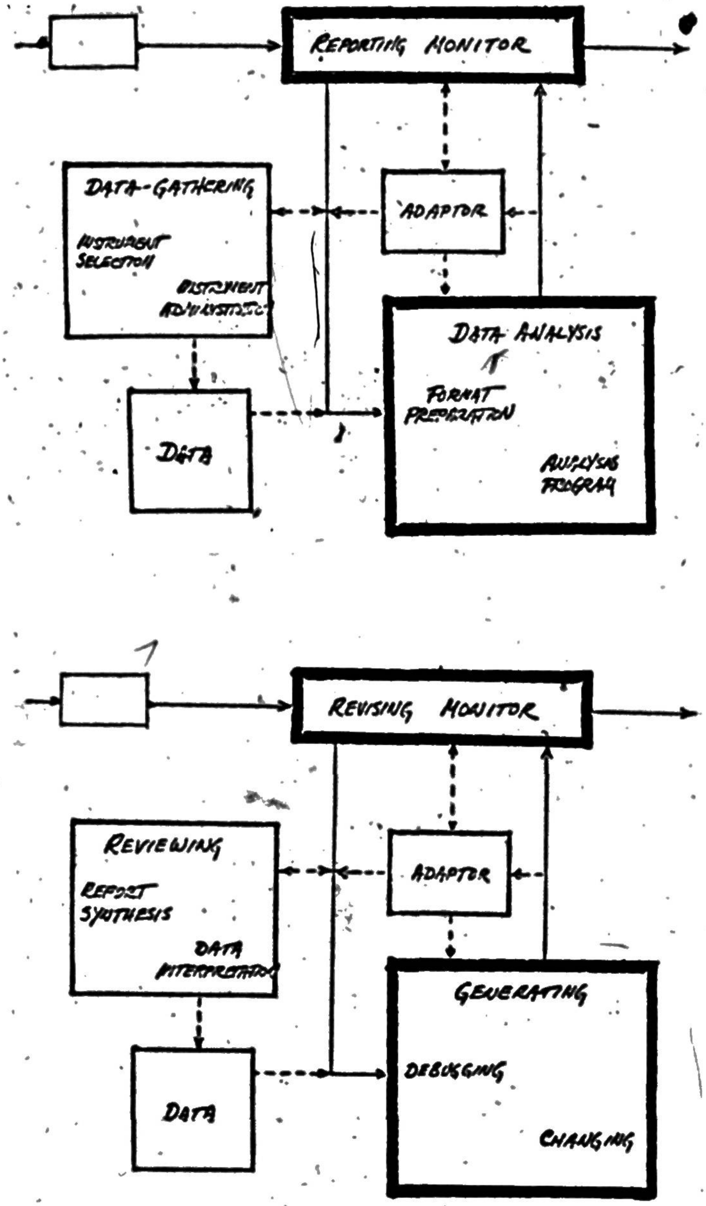

Figure 8. The preprocessor (reporting) and main processor (revising) of the redesign subsystem of GENTL. The functions of these processors are found at every level and every component of binary-adaptive loops within GENTL and are responsible for making the teaching-learning process adaptive.

Two properties permeate GENTL. First, components tend to be isomorphic to the overall system. Like nested TOTEs, each with test-operate phases, the subsystems of GENTL each contain a monitor and a BAL, Second, the system tends to be recursive, with subsystems activating themselves. The process therefore turns in upon itself, winding its way toward a deep structure of TLP relationships, then unwinding to generate a variety of actions and solutions.

Isomorphism in the design subsystem means that counterparts can be found to the monitor-BAL relationships at the top level (Figure 2). The design monitor, like the global system monitor, maintains the belief system that guides planning. Like a block structure computer program, some data known to the design monitor is unique to the planning process, but a great deal is held in common with the global monitor. To the facts, knowledge and cognitive structures that make up the system memory, the design monitor has added specialized techniques and histories related to planning processes in the past. From the values, hopes, and fears of the system expectancy, the design monitor has selected particular goals and criteria, forming its own expectancy with special attention to standards that relate to output from the design subsystem (e.g. the form and sequencing of lesson materials).

Elements of the design BAL, like the system BAL, consist of a preprocessor, an agent to be transformed, a main processor,and an adaptor. The preprocessor is the envisioning subsystem that sets up objectives and structures them into a coherent lesson framework. The agent is the learning environment that must be shaped into a suitable vehicle for the lesson. The main processor is the provisioning subsystem that selects appropriate media and arranges them into a lesson module. The adaptor, like the design monitor, performs the same function as its counterpart at the global level but with access to the local, design-specific data in the design system memory and expectancy.

The Isomorphic character of the subsystems leads to a similar analysis of the learner, the delivery subsystem, and the system adaptor or redesign subsystem (Figure 3). The learner briefly, has memory and expectancy, along with other components of a monitor, and a BAL consisting of perception (preprocessor), task (agent), response (main processor), and adaptor. Delivery, like design, has a local monitor that oversees engaging, learner-responding, replying, and adapting. Redesign revolves from data-gathering/reporting to audience-consulting to revising/remediating to feedback review.

The analysis can proceed to lower levels (Figure 4). Envisioning begins with the stating of objectives, consults task characteristics, structures a framework, and adapts to student entry levels and monitor criteria. The stating of objectives is itself a subsystem that first specifies outcomes or experiences, then examines conditions for their occurrence, specifies the cues that will be needed, and finally establishes criteria that indicates attainment of the objectives.

This analysis of a process in terms of itself is a type of recursive definition and theoretically could continue into infinity. The depth of recursion is limited in practice by time, by the capacity of the analyst to maintain pointers to each of the intermediate levels, and by the difficulty of the top-level task. Use of recursion is a form of problem-solving, since each level breaks down the overall problem into increasingly more manageable components, The depth of recursion is one index of problem difficulty.

A full elaboration of each subsystem in GENTL is beyond the scope of this paper, but the effect of recursive definition is suggested by Figures 5 - 8. Through what Ausubel calls "progressive differentiation" (Ausubel, 1963), these figures open up second level subsystems to reveal third and fourth level operations. On the basis of output from envisioning and input from an audience (e.g. colleagues), the preparatory phase in provisioning (Figure 5) is the identification and configuration of lesson materials. The consummatory phase then uses data about the student audience to establish the appropriate environmental conditions (parameter-settings) and match students to module activities.

Engaging, the initial process in delivery, breaks down into sub-processes of cueing and probing (Figure 6). Both manipulate pre-response stimuli by selecting and highlighting critical features of the lesson environment. They differ in that probing incorporates past responses into the cueing process, enlarging the range of stimuli by extending it forward in time.

The discussion to this point has considered recursion only within a hierarchical, vertical framework. Non-hierarchical network recursion, which can extend horizontally, often plays a prominent role in the major delivery process, replying (Figure 7). Following a student response, the teacher's response, or reply, ordinarily follows a careful analysis involving diagnosis and prescription. Diagnosis edits or maps the response onto some template of teacher expectations, then examines the response in detail. Before completing the analysis, the diagnostician may frequently reenter the probing subsystem, return for diagnosis, perhaps reenter probing, and return once again - each call of the diagnostic process occurring at a deeper level. In a like manner, prescription may invoke the cueing system to explain and provide feedback, then call itself through the cueing system to provide feedback about elements in the original feedback.

Another, perhaps more significant example of network recursion is the role of the adaptor. This component has a double life. Along with a monitor, it exists in every subsystem to facilitate what Ausubel calls "integrative reconciliation" in the system as a whole (Ausubel, 1963). The adaptor is a quality control device, a trouble-shooter to identify and correct system failures, and a vehicle for maintaining communication and compatibility among the parts. But the adaptor exists in its own right as the redesign subsystem. It has a pre-audience reporting phase, which gathers and interprets data, and it performs revision by reviewing the entire TLP according to that data, proposing changes where "bugs" are found (Figure 8). This pivotal adaptive process, so often neglected, is the central recursion in a generative system. It might be said that a system is generative in so far as the monitor places policy and control in the hands of the adaptor, so that the adaptor is free to generate change at every level.

Implications of GENTL for research are as far-reaching as they are for practice. Besides organizing research on the TLP into a holistic framework, something like the GENTL model is needed for taking into account the complexity and creativity of the TLP. Research needs to recognize dynamic properties of psychological behavior that spring from internal variables in interaction with conveniently quantifiable external variables. A deep-running theoretical base is one of the major missing ingredients in current educational research (cf. Suppes, 1975).

For practice a model like GENTL is a reminder that competence in teaching is much more than behavioristic outcomes and more even than adaptivity. The TLP is a richly interrelated system only crudely and often mistakenly represented by the linear lesson plans and flow charts that abound in teacher training literature. Based on a generative model that identifies the competencies of the underlying subsystems, teacher training could be oriented toward creative problem-solving through recursive use of these generic functions identified in GENTL.

Both research and practice can benefit by viewing the student as an agent actively involved in the transformation process. Indeed, the learner may begin as one component of the overall process, but the ultimate goal of a generative model is to move the learner up through the other components until each has been internalized and the learner can become self-teacher. A society of self-transforming, self-renewing citizens is probably the best generative model we can hope to find.

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